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THE CMS CRYSTAL CALORIMETER FOR THE LHC

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The CMS crystal calorimeter, comprising about 80.000 scintillating lead tungstate crystals read out by avalanche photodiodes in the barrel and vacuum phototriodes in the endcap, is designed to give excellent energy resolution in the LHC environment. We are now entering in the construction phase. We present here a status report on the project, with recent results on tests beam, crystal production and photodetector choice.

1 Introduction

The Compact Muon Solenoid (CMS) experiment [1] will build a general-purpose detector designed to exploit the physics of proton-proton collisions at a centre-of-masse energy of 14 TeV over the full range of luminosities expected at LHC. The CMS detector is designed to measure the energy and momemtum of photons, electrons, muons and other charged particles with high precision.

1.1 Physics at CMS

CMS will be used for Higgs searches, on the context of both Standard model and non-minimal models. It will also be used for other new particle searches (for example supersymmetric particles), b physics and heavy ion physics.
The CMS electromagnetic calorimeter is well adapted for Higgs searches at low luminosity, in a mass region between 100 and 150 GeV/c^2. The particle is mainly produced via gluon-gluon fusion, and in this range of mass a clean signature of the Higgs will be its decay into two photons. The theoritical width of the Higgs is still relatively small ($< 20\ MeV$), so that measurement will be dominated by the experimental resolution. This need of excellent resolution has motivated the choice of an homogeneous rather than sampling calorimeter.

1.2 The choice of the electromagnetic calorimeter

The CMS ECAL comprises a barrel ($|\eta < 1.479$) and two endcaps. The active medium is made of lead tungstate ($PbWO_4$) scintillating crystals. The light produced by an incident particle is read by avalanche photodiodes (APD) in the barrel and vacuum phototriodes (VPT) in the endcaps. The photodetectors are followed by a preamplifier and a floating point sampling ADC. Then, the digitized samples are serialized and brought out of the detector via an optical link. All the electronic components are radiation hard.
The resolution of a calorimeter can be parametrized by the formula :

$$\frac{\sigma}{E} = \frac{a}{\sqrt{E}} \oplus b \oplus \frac{c}{E}$$

with the stochastic term a, the constant term b and the eletronic noise term c (2.7%,0.55%,200MeV for the barrel).
If these specifications are met, it will be possible to discover the Higgs in CMS during the low luminosity period in the 100-150 GeV region, using the 2-photon decay channel.

2 Status of ECAL

We have now started the production phase. The next items show the status of different ECAL components.

2.1 The lead tungstate crystals

Results from the batches of production crystals from Russia [2] (3.500 in April 2000) are very encouraging. The main crystals measurements, done at CERN by a machine named ACCOS, show that only few percent are rejected, due to bad light yield ($< 8\ pe/MeV$ at $8\ X_0$, see figure 1) or bad radiations hardness (Light Yield loss$>$ 4 %).

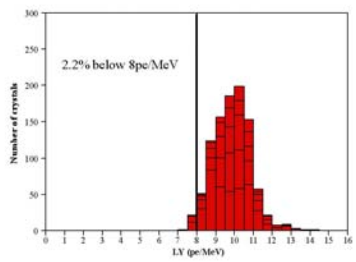

Figure 1. Distribution for 1000 crystals of light yield measurements done by ACCOS machine

2.2 The photodetectors

The photo-detectors have to operate in a 4T magnetic field. In the barrel, Avalanche Photodioes (APDs) delivered by Hamamastu are used. Two 25 mm^2 APDs are glued to the rear face on each crystal. The first production run (3.500 pieces) is arrived in June 2000. The main characteristics to control are gain versus bias, radiation hardness, breakdown bias and capacity.

2.3 Readout of the photodetectors

Scintillation light from the crystals is converted to a current by the photodetectors and shaped to a voltage pulse by the preamplifiers. The voltage pulse is digitized at 40 MHz by a floating point ADC. A 2^{17} dynamic range is achieved using a 12-bit ADC and four ranges. The digital values are transmitted to a counting room on high-speed optical links. The front-end electronics must all tolerate a harsh radiation environment - up to 100 kGy and $10^{14}\ n/cm^2$ for ten years LHC running in the end cap. The complete front-end power consumption is a litlle over 1 W per channel. The design of the complete, radiation hard, electronics chain is now complete.

2.4 ECAL Structure

For the ECAL barrel, we have $360(\phi) \times 2 \times 85\ (\theta)$ crystals. The smallest ensemble is a submodule of $2(\phi) \times 5\ (\theta)$ crystals put in a reflective alveola. With 40 or 50 submodules, we obtain a module ; with 4 modules of 400 crystals and 1 module of 500 crystals, a supermodule. With 36 supermodules, we have the ECAL barrel.
A double cooling system enables the evacuation of the heat produced by the electronics. The temperature sensitivity of crystals and APDs requires a temperature stability of $0.1\ ^oC$ at $18\ ^oC$.
The endcaps structure is more simple : 2 dees of 7810 crystals grouped into supercrystals of 5×5 crystals.

3 Beam Tests and Calibration

3.1 Beam tests in 1999 and 2000

In 1999, a prototype of 30 channels was build with pre-production crystals and APDs, dedicated to noise studies and energy scan. The noise was found of 36 Mev or 10.530 e^- by channel. The light yield measurement done in beam or in ACCOS are in good agreement. We obtain a mean stochastic term of 2.74 %, a constant term of 0.41 % and an electronic noise term of 142 MeV, for a sum of 9 channels, centering of deposited energy maximum. The figure 2 shows reconstructed energy distribution with 280 GeV electrons beam.
In May-June 2000, a similar prototype was done, but dedicated to monitoring and calibration studies. The figure 3 shows the laser and beam respons of a crystal during irradiations cycles. For all crystals, we obtain a very good correlation between laser and beam, with a laser stability better than 0.4 %.
In the same way, in July 2000, a same pro-

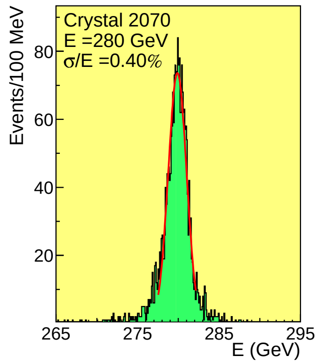

Figure 2. Reconstructed energy with 280 GeV electrons incident on barrel prototype matrix

totype with Chinese crystals will be tested, and in August 2000, a prototype with final electronics readout.

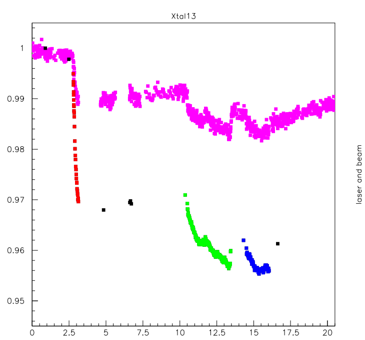

Figure 3. Laser and Beam Respons of a crystal during irradiations cycles

3.2 Monitoring and Calibration

To have the required resolution on the measured energy, it is very important to perform a precise calibration of the calorimeter. Before its installation on the LHC site, each module will be placed in electrons test beam for a precalibration of each crystal at 2 energy points.

During the run of the CMS experiment, a light monitoring system will track the behaviour of each channel. It is well establiesched that radiation only affects light transmission in the crystal, and not the scintillating process itself, so there is a relationship between the response to incident particles and the response to an injected light on the crystal front face.

A laser system will send two wavelengths (red and green) to the front face of each crystal and to reference PIN photodiodes. This sytem will provide a way to monitor with precision the calibration constants.

But the physics processes ($W \rightarrow e\nu$ and $Z \rightarrow e^-e^+$) will be used to calibrate the calorimeter during the running periods.

Combining these methods, it will take approximately 35 days at low luminosity to have a calibration at the level of 0.3 %.

4 Conclusion

Five years of intensive R&D on the CMS electromagnetic lead tungstate crystal calorimeter have resulted in a design that can meet the challenging LHC requirements. Mass productions of crystals, APDs and soon readout electronics is underway. This signals the start of the construction phase. In 2001, will be tested a Module of 400 crystals, with final mechanic, electronic and be constructed the first Super-Module of 1600 crystals.

Acknowledgments

I would like to acknowledge all CMS ECAL collaborators.

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2. Status of barrel Crystal Preproduction in Bogorodisk,*private communication*, E. Auffray, June 2000.